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probable error of the result; showing that the tail did not coincide with the radius-vector of the comet.

The whole head was so bright that even on the six-minute plate the nucleus has disappeared from over-exposure. An exposure of less than a minute would probably have been sufficient to show the nucleus alone.

A PRELIMINARY DETERMINATION OF THE MOTION OF THE SOLAR SYSTEM.*

BY W. W. CAMPBELL.

The first investigation undertaken with the Mills spectrograph, in May, 1895, related to the determination of the radial velocities in the system of *Saturn*.† It confirmed, in all respects, the noted results announced by Professor KEELER a few weeks earlier. Determinations of stellar velocities were now undertaken, and results of considerable accuracy were at once obtained. The observed velocities of a bright solar type star could be depended upon to fall within a range of five or six kilometers. However, it soon became apparent that the instrument contained many defects. Some of these, with their remedies, have been described in my article on "The Mills Spectrograph," in the *Journal* for October, 1898; but the large majority were purely local, and do not call for special comment. The greater part of the first year was devoted to isolating and eliminating these defects; and it was not until the summer of 1896 that results considered satisfactory for publication were secured. Added precautions taken, and improvements made in the instrument and methods, have shown corresponding and gratifying increase of accuracy from year to year.

Following the methods of observation already described in the *Journal*, two thousand spectrograms have been secured since the summer of 1896. These include: plates of the solar spectrum for determining the camera-focus and scale-values; plates of stellar spectra for determining the focus of the 36-inch objective

* Reprinted from the *Astrophysical Journal* for January, 1901.

† *Astrophysical Journal*, August, 1895, pp. 127-135.

at different temperatures; plates of comparison-spectra, etc.; perhaps one hundred stellar spectrograms rejected for cause, without measurement; and in the neighborhood of fifteen hundred satisfactory spectrograms of about three hundred and twenty-five stars, situated between the North Pole and Declination -30° . At least three or four hundred of these photographs relate to spectroscopic binaries, for some of which, such as ζ *Geminorum*, nearly fifty plates were needed.

It is not practicable to publish the observed velocities at the present time, for two reasons:—

(a) Many of the plates have been only partially measured, and reduced by approximate methods. Experience shows that these approximate results may be changed as much as $1\frac{1}{2}^{\text{km}}$ by the final measures and reductions, though the average change is much less.

(b) The reductions have not been based upon the definitive wave-lengths of the solar and comparison lines. These are not yet available, but they are expected soon.

Repeated requests have been made that the observations already secured should be used to determine the motion of the solar system with reference to the system of observed stars; and it is the purpose of this article to communicate the preliminary results of such an investigation.

Omitting several Type I stars whose lines could not be accurately measured, and some thirty spectroscopic and visual* binaries for whose centers of gravity the velocities are not yet known, there remain 280 stars available for determining the relative motion of our system. Inasmuch as this number is constantly increasing with the progress of the observations, and in a few years will, I hope, be doubled, and include stars distributed over the entire sky, it did not seem necessary to form an equation of condition for each star. The 280 stars were divided into 80 groups, by combining neighboring stars into one group; taking the mean of their individual velocities as the velocity of the group. The data for each of the 80 groups are contained in the first four columns of Table I.

Let v be the observed speed of a star with reference to the solar system; V the Sun's speed with reference to the system of 280 observed stars; and D the angular distance of a star from

* Such as *Sirius*, *Procyon*, etc.

the apex of the solar motion. Then each star, or each group of stars, furnishes an equation of condition having the form:—

$$V \cos D - v = 0. \quad (1)$$

Let α_0, δ_0 be the coordinates of the apex, and α, δ those of the star; then we have $\cos D$ defined by the well-known equation for the distance between two stars or points,

TABLE I.

No. of Stars.	Mean R. A.	Mean Dec.	Mean Observed Velocity.	No. of Stars.	Mean R. A.	Mean Dec.	Mean Observed Velocity.
	h m	°	k		h m	°	k
2	0 26.5	—14.0	+17.0	3	12 20.4	+43.0	—4.7
6	0 40.0	+57.8	—10.3	3	12 35.7	—22.5	—1.7
5	0 45.0	+28.2	—24.2	3	12 48.1	+4.9	—17.0
3	1 23.0	—10.1	+12.7	2	13 6.2	+23.2	—8.2
4	1 35.5	+43.9	+0.2	2	14 9.2	—7.6	+3.0
3	1 43.7	+10.6	+7.3	5	14 14.9	+18.1	—3.9
2	1 47.4	—19.0	+2.5	2	14 29.5	—25.6	+11.8
2	2 2.6	+24.2	—19.0	7	14 58.0	+29.6	—13.1
9	2 38.5	—14.1	—3.2	4	15 2.4	+46.0	—28.5
3	2 54.4	+0.1	+21.7	4	15 23.2	+4.8	—7.0
5	2 55.4	+50.2	+13.6	4	15 27.4	+65.8	—14.2
4	3 3.8	+41.2	+4.5	4	15 41.4	—12.9	—1.0
3	3 16.9	+13.6	+6.7	4	16 17.1	—20.8	—11.1
3	3 45.8	—9.2	—10.7	4	16 32.8	—8.5	—7.0
3	4 3.2	—17.3	+34.8	3	16 38.0	+13.3	—26.0
5	4 16.6	+18.0	+35.5	3	16 49.5	+35.9	—29.0
2	4 29.7	+79.8	—3.0	3	17 44.7	+53.6	—22.3
4	4 46.8	+44.7	+8.2	4	17 53.6	+29.5	—9.9
3	5 15.7	+37.4	+30.7	3	17 53.8	+5.3	—7.5
2	5 17.0	+7.1	+22.0	6	18 18.6	—7.2	—5.4
4	5 23.5	—20.9	+1.8	6	18 36.4	—23.5	—23.5
3	5 32.6	—7.5	—0.7	3	18 38.6	+19.0	—28.5
3	5 51.5	+57.7	+5.0	2	18 43.0	+41.2	—20.5
4	6 18.1	+25.0	+24.8	6	18 48.9	+69.6	+6.4
2	6 41.0	—15.6	+50.5	4	19 42.1	+6.2	—19.9
3	6 43.3	+16.7	+6.3	5	19 42.6	+23.6	—11.6
3	7 32.4	+27.0	+11.3	4	20 3.6	+55.4	—44.2
2	7 33.8	—25.1	+42.0	3	20 19.3	—9.1	—8.7
2	7 47.0	+9.3	+34.0	3	20 48.9	+43.3	+1.0
2	7 50.6	—6.0	+21.0	5	20 58.5	+12.8	—28.2
4	8 56.6	+10.5	+26.9	5	21 1.3	+31.9	—2.6
2	8 57.8	+32.0	+25.2	4	21 24.6	—15.8	—2.9
4	8 58.0	+65.7	—4.0	3	22 00.2	+12.7	—7.3
2	9 10.2	+47.2	+19.0	2	22 13.6	+54.7	—14.2
3	9 27.2	—3.7	+12.3	4	22 32.6	—6.7	—11.3
2	9 57.2	+22.3	—15.2	5	22 52.9	+25.4	—0.2
5	10 40.2	—15.2	+19.6	2	23 10.6	+71.4	—26.5
5	10 44.7	+38.1	—2.8	4	23 10.7	—18.7	+5.6
2	11 11.6	+66.1	±0.0	2	23 16.0	+43.8	—2.0
6	11 32.8	+6.2	+3.7	4	23 31.0	+5.0	—0.9

$$\cos D = \sin \delta_0 \sin \delta + \cos \delta_0 \cos \delta \cos (\alpha_0 - \alpha). \quad (2)$$

If we place

$$\left. \begin{aligned} x &= V \sin \delta_o \\ y &= V \cos \alpha_o \cos \delta_o \\ z &= V \sin \alpha_o \cos \delta_o \end{aligned} \right\} \quad (3)$$

equations (1) take the form

$$\sin \delta \cdot x + \cos \alpha \cos \delta \cdot y + \sin \alpha \cos \delta \cdot z - v = 0 \quad (4)$$

from which the values of x , y , and z may be determined; and the values of V , α_o , and δ_o may then be found from (3) by the relations

$$\left. \begin{aligned} V^2 &= x^2 + y^2 + z^2 \\ \tan \alpha_o &= \frac{z}{y} \\ \sin \delta_o &= \frac{x}{V} \end{aligned} \right\} \quad (5)$$

The values of α and δ for each group were substituted in equation (4), and the resulting equation was weighted in proportion to the number of stars on which it is based, as indicated in column one of the table. The eighty equations thus formed were combined and solved by the method of least squares, and the following elements of the solar motion were obtained:—

$$\begin{aligned} V &= - 19.89^{\text{km}} \pm 1.52^{\text{km}} \\ \alpha_o &= 277^\circ 30' \pm 4^\circ.8 \\ \delta_o &= + 19^\circ 58' \pm 5^\circ.9 \end{aligned}$$

The list of stars employed in this investigation includes all that were available; none were rejected arbitrarily, on account of very high speed or otherwise. The results represent the solar motion relative to the entire system of observed stars. Had a dozen stars of great velocity been rejected, the speed and direction of the motion would have been only slightly different, but the computed probable errors would have been very much smaller than those appended.

On the basis of these elements, the component correction for the solar motion was computed and applied to each star. The 280 results obtained in this manner represent the individual stellar components of motion in the line of sight, with reference to the entire system. Of these there are

	Km per second.
151 positive, average,	+17.01
129 negative, average,	-17.10
280 numerical average,	17.05

The average component velocity of each star in a plane at right angles to the line of sight is therefore

$$\frac{\pi}{2} \cdot 17.05 = 26.78^{\text{km}} \text{ per second;}$$

and the average velocity *in space* of each star in the system is

$$2 \times 17.05 = 34.10^{\text{km}} \text{ per second.}$$

The Sun's relative velocity, 19.9^{km} , is therefore much smaller than that of the average star of the system, 34.1^{km} .

The 280 stars were classified roughly, according to their spectral types, in the following manner: the *Harvard Photometry* contains estimates of their brightness, based upon the visual radiations. The *Draper Catalogue* estimates their brightness by virtue of the photographic intensities of their spectra in the *H γ* region. The difference between the visual and photographic magnitudes is very small in the case of the white stars, such as β *Orionis*; it is usually from 1.5 to 2.0 magnitudes for the solar type stars, such as β and γ *Andromedæ*; and is fully 2.5 magnitudes for red stars, such as α *Scorpii*.

In the system of stars observed, the difference of magnitude is equal to or greater than 1.0 for 144 stars. Subdividing these according as their component velocities in the line of sight are positive or negative, we have

78 positive, average component, $+ 17.07^{\text{km}}$	
66 negative, average component, $- 14.99$	
144 numerical average, ...	16.12

For 136 stars the difference of magnitude is less than 1.0, as follows:—

73 positive, average component, $+ 16.94^{\text{km}}$	
63 negative, average component, $- 19.32$	
136 numerical average, ...	18.04

The discrepancy of 1.9^{km} in the results is hardly sufficient to justify any statement as to the effect of spectral type upon velocity.

The relations between visual brightness and velocity was next investigated.

Of stars equal to or brighter than 3.0 magnitude, there are

26 positive, average component, $+ 13.11^{\text{km}}$	
21 negative, average component, $- 12.99$	
47 numerical average, ...	13.05
Corresponding velocity in space,	26.10

Of stars lying between magnitudes 3.1 and 4.0 inclusive,
 there are 59 positive, average component, $+ 17.70^{\text{km}}$
 53 negative, average component, $- 14.42$

 112 numerical average, ... 16.15
 Corresponding velocity in space, . 32.30

Of stars fainter than 4.0 magnitude, there are

 66 positive, average component, $+ 17.93^{\text{km}}$
 55 negative, average component, $- 21.27$

 121 numerical average, ... 19.44
 Corresponding velocity in space, . 38.88

The progression in these results is so pronounced, and the differences are so large, that I think we are justified in drawing the important conclusion that the faint stars of the system are moving more rapidly than the bright stars. This apparent fact, derived quite independently of any assumption as to the relative distances of the stars of different magnitudes, should profoundly affect the question of and the methods of determining the structure of our sidereal system. If the fainter stars are moving relatively more rapidly than has been previously assumed, they must be relatively farther from us than the investigations of their proper motions have led us to conclude.

This progression is in no wise due to an increase of probable error of a velocity determination with decreasing magnitude. The probable error of a single determination is well under half a kilometer for such excellent stars as *Polaris* and *Procyon*; and it is not much greater for fifth-magnitude stars whose spectra contain well-defined lines.

The elements of the solar motion deduced above depend upon the assumption that their most probable values are those which make the sum of the squares of the residual stellar components of speed in the line of sight a minimum. This, in turn, assumes that the magnitudes of these components are distributed according to the law of accidental errors. No doubt they are distributed according to a somewhat different law, which I hope to investigate fully a few years later, before making a definitive determination of the motion, based upon a much larger number of stars distributed over the entire sphere.*

* An additional reason for delay arises from the fact that many years of observation are required to establish constancy of stellar velocities, in some cases; of the stars used in the above determination, two have since been discovered to have variable velocities.

The Right Ascension of the apex, $277^{\circ} 30'$, agrees exactly with the value deduced by Professor NEWCOMB* from all the "proper motion" data available; and differs only $1^{\circ} 30'$ from Professor KAPTEYN's† assumed value, 276° . My value of the Declination $+19^{\circ} 58'$, differs widely from NEWCOMB's value, $+35^{\circ}$, and KAPTEYN's, $+34^{\circ}$. It must be noticed that very few radial velocities are available for the region -15° to -30° , and none whatever south of -30° Declination. Fully one third of the sky is unrepresented in the solution. The data for determining the Declination of the apex are extremely unsymmetrical in arrangement. The data north of the line of motion are fairly complete, whereas the data to the south are very incomplete. To determine the Declination therefrom is somewhat similar to flying with one wing very imperfect. The Right Ascension, on the contrary, is determined from data reasonably symmetrical in distribution.

A comparison of my results with those obtained by STUMPE‡ from proper motions is of great interest. He classified the stars of relatively large proper motions according to their visual magnitudes, with the following results for the position of the apex:

No. of Stars.	Magnitude.	R. A.	Dec.
284 . . .	1 to 5.5	$263^{\circ}.8$	$+31^{\circ}.1$
473 . . .	5.6 to 7.5	290.7	$+37.5$
238 . . .	7.6 to $>$	286.7	$+46.9$

In view of these widely different positions of the apex, it is perhaps not surprising that my result for Declination, depending upon even brighter stars than his first group should be smaller than any hitherto obtained.

The motion of the solar system is a purely relative quantity. It refers to specified groups of stars. The results for various groups may differ widely, and all be correct. It would be easy to select a group of stars with reference to which the solar motion would be reversed 180° from the values assigned above. It is perhaps unsafe to draw conclusions, from my value of the Declination, concerning the drift of the brighter (and presumably nearer) stars until the data from the southern sky are available.

Before making the preceding solution for the solar motion by the method of least squares, I had already made an approxi-

* *Astronomical Journal*, No. 457, pp. 4, 5.

‡ *Astronomical Journal*, No. 457, p. 5.

† *Astronomische Nachrichten*, No. 3487, p. 104.

mate determination of the speed of the solar system, by a different method, as follows: the apical distance D of each star was computed from NEWCOMB's assumed coordinates of that point ($\alpha = 277^\circ.5$; $\delta = +35^\circ$). The stars were formed into groups according to their apical distances, as indicated in the first column of Table II. The number of stars in each group is given in column two. The mean apical distance of the group is $[D]$ and the mean observed velocity is $[v]$. It is interesting to note that each $[v]$ between apical distances 0° and 90° is negative, and each one between 90° and 180° is positive. Each radial velocity furnishes an equation of condition of the form

$$V - v \sec D = 0, \quad (6)$$

from which to determine V . We shall assume that the weight of each determination is equal to $\cos D$. The resulting value of V will now be given by

$$V = \frac{\sum (n \cos [D] \cdot [v] \sec [D])}{\sum n \cos [D]} = \frac{\sum n [v]}{\sum n \cos [D]}. \quad (7)$$

Substituting the values of n , $[v]$, and $[D]$ in this equation, I obtained

$$V = -20.4^{\text{km}}.$$

TABLE II.

Apical distances.	n	$[D]$	$[v]$	$\cos [D]$
$0^\circ - 10^\circ$	4	7.4	-9.9	+0.992
10 — 20	10	15.5	-24.0	+ .964
20 — 30	16	24.7	-17.5	+ .908
30 — 40	24	34.8	-12.9	+ .821
40 — 50	24	44.1	-16.6	+ .718
50 — 60	29	54.6	-6.1	+ .579
60 — 70	29	64.4	-7.0	+ .432
70 — 90	47	79.7	-2.7	+ .179
90 — 110	35	99.4	+8.0	- .163
110 — 120	19	116.3	+14.4	- .443
120 — 130	18	124.4	+13.8	- .565
130 — 140	10	134.4	+16.4	- .700
140 — 150	5	145.1	+14.6	- .820
150 — 160	6	156.0	+29.3	- .914
160 — 170	4	164.0	+6.0	-0.961
	280			

$$V = \frac{\sum n [v]}{\sum n \cos [D]} = \frac{-3010}{147.5} = -20.4^{\text{km}}.$$

If we use this value of V as a basis for further approximations to its true value, by the method of KAPTEYN,* we shall obtain $V = -19$ kilometers; though it should be said that this method involves assumptions concerning proper motions.

The foregoing data bear decisively upon the question of stellar parallaxes and other fundamental problems; but these portions of the subject are reserved for a future paper.

The work with the Mills spectrograph has furnished many important by-products. Special mention may be made of the discovery of an unexpectedly great number of spectroscopic binaries. Two or more satisfactory observations have been secured for each of 285 stars of my programme. From the Mills spectrograph observations alone we have discovered that thirty-one† of these stars are spectroscopic binaries. To these we must add three binaries in the same list previously discovered by another observer,‡ making thirty-four in all. That is, of 285 observed stars, *more than one star in nine is a spectroscopic binary*. Further, five additional suspected binaries await verification, and it is altogether probable that many other stars in the list are binaries awaiting discovery. Two plates are not sufficient to detect variable velocity, even in many cases of short period; and still less are they sufficient in many cases of long period, now coming to light by virtue of our older observations. It is not improbable that at least one star in five or six will be found to be a spectroscopic binary; and I should not be surprised to see a still larger ratio established.

The proven existence of so large a number of stellar systems differing widely in structure from the solar system gives rise to a suspicion, at least, that our system is not of the prevailing type of stellar systems. The new field of astronomical research thus opened up is of great richness, and may well occupy the attention, for an indefinite period, of the large number of observers and institutions now engaging in its development. It is perhaps unnecessary to say that the measure of success attainable is

* *Astronomische Nachrichten*, No. 3487.

† Twenty-five of these have been announced in the *Journal*, and six now await announcement.

‡ Dr. BÉLOPOLSKY, at Pulkowa, α, *Geminorum*; the well-known variable stars δ *Cephei* and η *Aquilæ*; and the independent and prior discovery of the binary character of the well-known variable, ζ *Geminorum*.

dependent upon the degree of accuracy * realized in the observed velocities.

It is a pleasure to record that I have been assisted most efficiently in these investigations, since August, 1897, by Mr. W. H. WRIGHT, assistant astronomer.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA, December, 1900.

PLANETARY PHENOMENA FOR MAY AND JUNE, 1901.

BY MALCOLM McNEILL.

MAY.

There will be a very close approximation to a lunar eclipse at Full Moon on May 3d, the Moon passing within $1'$ of the Earth's shadow. At the succeeding New Moon, May 17th, there will be a total eclipse of the Sun. The line of totality lies in the southern hemisphere, and passes almost wholly through the ocean, but crosses the islands of Sumatra, Borneo, and New Guinea. The eclipse is remarkable on account of the great duration of totality, nearly six and one half minutes in some places, a duration four times as great as any available duration for the eclipse of May 28, 1900.

Mercury is a morning star at the beginning of the month, but passes superior conjunction on May 14th, and becomes an evening star. It moves rapidly away from the Sun, eastward and northward. Toward the end of the month it becomes a comparatively easy object in the evening twilight, not setting until an hour and a half after sunset.

Venus is now an evening star, having passed superior conjunction with the Sun on April 30th, but remains quite close to the Sun throughout the month. At the end of the month it sets only a little more than half an hour after sunset, and will be very hard to see.

Mars is still waning, increasing its distance from us 24,000,000 of miles during the month, and diminishing in brightness about

* In the later observations of the *best stars* with the Mills spectrograph, an extreme range of two kilometers would afford strong suspicion of variable velocity; and the greater portion of a smaller range due to unavoidable errors would arise not from errors in the spectrograms, I believe, but from changes in the observer's personal habits of measuring the plates.